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Recent contributions on Falkland Islands bedrock geology, with an inventory of representative lithostratigraphical specimens held by the British Geological Survey

Marine Geoscience Programme

Open Report OR/14/040

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P Stone

Keywords

West Falkland Group, Lafonia Group, Fitzroy Tillite, archaeocyath, ophiuroid, aeromagnetic survey, North Falklands Basin, Falklands Plateau Basin, Devonian, Permian, Gondwana.

Front cover

Crags of Port Stanley Formation quartzite at Mount Harriet, 10 km west of Stanley, seen from Wall Mountain, East Falkland.

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Foreword

This report arises from onshore geological investigations in the Falkland Islands, South Atlantic Ocean, carried out by the British Geological Survey on behalf of the Department of Mineral Resources, Falkland Islands Government. It provides background information on geological discoveries that have been made since completion of the Falkland Islands geological mapping project (1996-1998) and the publication of the ensuing map and report (1998, 1999). Some of the results mentioned arose from academic research and some from work by the author as part of a geological consultancy programme, led by Dr Phil Richards, supporting onshore mineral prospecting and offshore hydrocarbon exploration. Details are appended of a representative suite of specimens illustrating the onshore lithostratigraphy that is now held in the collections of the British Geological Survey, Keyworth, Nottingham, UK.

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Summary

After completion of the Falkland Islands geological mapping project in 1998, geological work on the islands by the British Geological Survey continued in support of onshore mineral exploration projects and to provide correlative data for the offshore hydrocarbons exploration programme. Academic research from British institutions has declined over the last decade, but international interest has increased, with research visits by geologists from Brazil, Australia and the USA. Results arising from these disparate sources have extended knowledge of the Falkland Islands lithostratigraphy, biostratigraphy and depositional palaeoenvironments, with the latter aspect extensively researched in relation to the glacigenic Fitzroy Tillite Formation. A representative suite of lithostratigraphic specimens has been placed in the BGS collections, Keyworth, as have a number of fossil specimens. The fossil fauna of the Falkland Islands has been extended by new discoveries in both the Devonian and Permian strata; noteworthy examples are the Devonian ophiuroid from the Fox Bay Formation, the Cambrian archaeocyaths in erratic clasts of limestone from the Permo-Carboniferous Fitzroy Tillite Formation, and the bivalve fauna from the Permian Brenton Loch Formation. Studies of structural geology have generally been complementary to work offshore, and have focused in particular on the thermal history experienced by the Falklands rock succession. Ar-Ar radiometric dating of syntectonic mica has confirmed an Early Permian age for the onset of deformation, later stages of which involved previously unrecorded sinistral shear. In terms of the regional geology, one tentative structural reinterpretation suggests that the southern extremity of the North Falklands Basin may extend onshore in the Limpet Creek area of the East Falklands coast. An aeromagnetic survey radically revised interpretations of the Falkland Islands dyke swarms; follow-up radiometric dating of dykes from East Falkland confirmed the Early Jurassic ages previously reported from West Falkland, but also proved the existence of a previously unsuspected Early Cretaceous swarm with ages from three individual dolerite dykes ranging from ca 135 Ma to ca 121 Ma. This newly discovered swarm comprises dykes aligned north-south across both West and East Falkland, and extends offshore to the south-east of the islands. The Jurassic and Cretaceous dykes onshore are compositionally distinct, and both suites have likely igneous correlatives offshore in the Falkland Plateau Basin. Scientific publications on the themes mentioned above have been supplemented by historical studies and more popular articles.

1 Introduction

The Falkland Islands lie in the South Atlantic Ocean, about 650 km east of the Strait of Magellan, at the western end of the Falkland Plateau, a rectilinear, relatively shallow water (<2500 m approximately) bathymetric feature that extends eastwards from the South American continental shelf (Figure 1a). Mesozoic sedimentary basins to the north (North Falklands Basin) and the south-east (Falkland Plateau Basin) of the archipelago are currently the focus of offshore hydrocarbons exploration within the designated Falkland Islands Exploration Area. The two principal islands are known as West Falkland and East Falkland (Figure 1b). Seen there, and on the surrounding smaller islands, is a clastic sedimentary sequence ranging in age from Siluro-Devonian to Permian that is cut by numerous dolerite dykes of Mesozoic age; the dykes are particularly numerous in West Falkland (Figure 1c).

The first recorded geological observations were made by Charles Darwin during two visits to the archipelago by HMS Beagle, in 1833 and 1834. Darwin described a folded and cleaved succession of quartzite, sandstone and mudstone, from which he recovered Devonian fossils (Darwin 1846; Morris and Sharpe 1846). In a footnote to his 1846 paper, Darwin recorded the dolerite dyke swarm that had been discovered and reported to him by Bartholomew Sulivan in 1845 (Stone and Rushton 2013). Little more was added until two Swedish expeditions visited the Falkland Islands: the Swedish South Polar Expedition (1901-1903) and the Swedish Magellanic Expedition (1907-1909). Reporting after these expeditions, Andersson (1907) and Halle (1911) recorded the presence on West Falkland of a Precambrian basement complex exposed at Cape Meredith (Figure 1b), improved the Palaeozoic stratigraphy and extended it into the Permian, and described a glacigenic tillite unit that Halle correlated with the Upper Carboniferous to Lower Permian Dywka Tillite of South Africa. This association of Falklands and South African geology had been noted much earlier on palaeontological grounds, and with evident surprise, by Sharpe and Salter (1856) and was reiterated by Clarke (1913) in his seminal work on the Devonian fauna of the Falkland Islands .

Although Halle (1911) had included an outline geological map of the Falkland in his report, the first attempt at comprehensive geological mapping was by Baker (1924) who acted as ‘Government Geologist’ from 1920 to 1922 but was principally concerned with mineral prospecting. In that respect he was unsuccessful, but his work laid the foundations for the modern interpretation of Falklands geology, and he notably utilised Wegener’s recently formulated ideas of continental drift to explain the geological similarities with South Africa. Wegener had championed the theory of continental drift from 1912, but it was not until 1924 that an English translation of his work was published, based on the third German edition of his book. Baker’s geological map was at a relatively small scale and was only available as a fold-out figure within an obscure report. Nevertheless, for fifty years it remained the definitive representation of Falkland Islands geology until the publication by the British Antarctic Survey of a photogeological interpretation by Mary Greenway (1972), who utilised much of Baker’s (1924) lithostratigraphy. In the interim, and with no additional fieldwork, Baker’s map and cross-section had been reproduced with minor amendments in a Spanish-language review by Borrello (1963) published in Argentina. The division of Baker’s specimen collection between The Natural History Museum, London, and Imperial College, London, was documented by Stone and Rushton (2006).

Following the appearance of Greenway’s map, a number of local projects were undertaken by visiting Argentine geologists, but this involvement came to an abrupt end in 1982 with the Argentine military invasion and subsequent recovery of the islands by British armed forces. The Argentine contributions have been summarised by Aldiss and Edwards (1999) whose work represents the next major advance in the understanding of Falkland Islands geology. As part of the post-conflict regeneration programme, the Falkland Islands Government commissioned a field-based geological survey which was carried out between 1996 and 1998 by Don Aldiss and Emma Edwards, supported by the British Geological Survey. The products were a published bedrock geology map in two sheets at a scale of 1:250 000 (Aldiss and Edwards 1998) and a comprehensive geological report (Aldiss and Edwards 1999).

Key features of Falkland Islands geology, as interpreted and described by Aldiss and Edwards 1998, 1999) and the researchers cited by them, are shown in Figure 2; the lithostratigraphy is summarised in Table 1. At the southern extremity of West Falkland, a small outcrop of Proterozoic crystalline basement – *Cape Meredith Complex* – comprises an assemblage of gneiss, granite and amphibolite, from which a number of radiometric dates have given an age of approximately 1100–1000 Ma. The Proterozoic rocks are unconformably overlain by a Silurian–Devonian succession of fluvial to neritic, clastic strata predominantly comprising quartzite, sandstone and mudstone. This succession is known as the *West Falkland Group*; it crops out over most of West Falkland and in the north of East Falkland. The south of East Falkland and its smaller peripheral islands are underlain by the tillite, mudstone and sandstone of the Carboniferous to Permian *Lafonia Group*. Pre-Devonian, mafic dykes cut the Cape Meredith Complex with widespread, polyphase swarms of mafic, Mesozoic dykes cutting the basement and all of the overlying sedimentary succession. At the time of the Aldiss and Edwards survey the Mesozoic dykes were known principally from West Falkland and were regarded as exclusively Jurassic. They are now known to be both Jurassic and Cretaceous in age, with the Cretaceous dyke swarm spanning equally across East and West Falkland (Stone and others 2008; Richards and others 2013). The new dyke data will be discussed in more detail later in this report.

Despite the proximity of the archipelago to South America, the geological association of the Falklands with the Cape Province of South Africa has long been recognized: the general similarities were appreciated by Halle (1911) and Baker (1924), the latter accounting for the similarities in terms of the then-radical theory of continental drift. However, the first proposal to move the islands into a geologically more explicable position came from Du Toit (1927) in whose reconstruction of Palaeozoic palaeogeography they were positioned much farther north, forming a structural link between the coeval and correlative Ventania and Cape Fold Belts of Argentina and South Africa respectively. Du Toit's solution did not find general favour and an alternative reconstruction was proposed by Adie (1952) wherein the Falkland Islands were rotated through 180^{o} into an original position adjacent to the east coast of South Africa. Palaeomagnetic results from the Jurassic dykes (Taylor and Shaw 1989) appeared to support that proposition, and the Falkland Islands are now commonly regarded as forming part of a microplate created and rotated during the break-up of Gondwana (Mitchell and others 1986; Marshall 1994; Storey and others 1999). Further evidence for rotation between intrusion of the Jurassic and Cretaceous dykes has been presented by Stone and others (2009) and will be discussed later in this report.

What follows hereinafter is a summary of the principal contributions to a geological understanding of the Falkland Islands that have arisen since completion of the Aldiss and Edwards (1998, 1999) survey. To complement the report a representative suite of rock specimens illustrating the Falkland Islands lithostratigraphy has been lodged in the collection of the British Geological Survey at the UK's National Geoscience Data Centre, Keyworth, Nottingham. Full details of the specimens are listed in Appendix 1.The lithostratigraphy used (Table 1) follows that established by Aldiss and Edwards (1998, 1999).

2 Cape Meredith Complex and Gondwana break-up

No new field or laboratory work has been reported from the Proterozoic, Cape Meredith Complex ‘basement’, but published data has been used by Ramos (2008) to reiterate the correlation with the Deseado Massif of Patagonia that was illustrated by Borrello (1963). Implicit in this correlation is rejection of the rotational model of a Falklands microplate detaching from the south-east side of South Africa as envisaged by Adie (1952). Instead, the Falkland Islands and the Falkland Plateau are seen as an original promontory from the South American continental margin, albeit one that has undergone much extension. This interpretation is also favoured by some researchers working with offshore geophysical data, for example Lawrence and others (1999). Conversely, Macdonald and others (2003) stress the convincing evidence for rotation of a Falklands microplate and accommodate that within a Gondwana break-up model that treats South America as a mosaic of four separate plates. A recent review by Dalziel and others (2013) also incorporate a ‘Lafonian’ microplate, rotating from an original position to the south-east of South Africa, in their reconstruction of the opening of the South Atlantic and genesis of the Scotia Arc. Note that Dalziel and others prefer the term ‘Lafonian microplate’ to ‘Falklands microplate’ – most probably as an apolitical name avoiding the Falklands-Malvinas controversy.

3 West Falkland Group

3.1 LITHOSTRATIGRAPHY AND PALAEOENVIRONMENT

Overlapping with the Aldiss and Edwards survey was field work by N. S. Meadows, who published independently (Meadows 1999) but acknowledged the assistance provided by Don Aldiss. Nevertheless, Meadows based his account on the Greenway (1972) geological map in which the northern part of East Falkland is shown as being underlain by the Port Stanley Formation. He used the lithostratigraphical divisions Gran Malvina Group (following Marshall (1994) and the Argentine literature) and Lafonia Supergroup (following Greenway). Aldiss and Edwards (1998, 1999) erected the replacement lithostratigraphical units West Falkland Group and Lafonia Group, and identified the Port Stephens Formation as underlying the northern part of East Falkland. Meadows described the two units in terms of transgressive-regressive sedimentary cycles. Within the West Falkland Group, the lowest formation, Port Stephens, was interpreted as the result of a marine transgression across an erosion surface in the Cape Meredith Complex basement with deposition mostly in an upper shoreface environment. Meadows proposed that shallow marine conditions then pertained during deposition of the Fox Bay Formation (shallow marine shelf) and Port Philomel Formation (delta front mass-flow). The overlying Port Stanley Formation was described as the deposits of a fluvial channel system which prograded across the Falklands during marine regression. The Lafonia Group was also referred to a transgressive-regressive cycle, commencing with glacigenic deposits, then passing upwards through lacustrine, shallow marine and deeper marine strata before culminating in fluvial channel deposits. Meadows supported the close association of the West Falkland Group with coeval lithostratigraphical units in South Africa, but regarded the Lafonia Group as less correlative with South Africa than had been previously supposed.

A detailed study of the Port Stephens Formation by Hunter and Lomas (2003) led to the recognition of a more complex interplay of sub-environments than had been recognised by either Meadows or by Aldiss and Edwards. Thirty five distinct lithofacies were identified which, together with their associated ichnofauna, were related to deposition on an extensive, gently-shelving alluvial to coastal plain. Within an overall transgress-regressive-transgressive sedimentary pattern the bulk of the sediment accumulated during the regressive phase. Hunter and Lomas stressed the correlation of the Port Stephens Formation with the Nardouw Subgroup of South Africa and considered that sediment distribution patterns were most compatible with a palaeogeography in which the Falklands were rotated to the south-east of South Africa, i.e. the Adie (1952) model. Eustatic sea level changes were thought to be a significant influence on the sedimentary pattern.

3.2 BIOSTRATIGRAPHY AND PALAEONTOLOGY

The Mid-Devonian (Emsian-Pragian) fauna of the Fox Bay Formation has a wide distribution in both East and West Falkland and has been much collected and described since its discovery by Charles Darwin in 1833. Substantial collections are held by museums in UK, USA and Sweden (Stone and Rushton 2012) and by the British Geological Survey (Stone 2012). A summary faunal list was given by Aldiss and Edwards (1999, Table 2), but several new discoveries can now be added.

In February 2000, a fossil collecting expedition from the American Museum of Natural History, New York, visited a number of sites in both East and West Falkland and made several new discoveries. Maisey and others (2002) described sparse fish remains: spines and a tooth whorl from the Fox Bay Formation at Roy Cove, and part of a cranial plate from the overlying Port Philomel Formation (Givetian?) at Dunnose Head, both West Falkland. Maisey and others noted that the fish remains were the first documented Devonian vertebrates found in the Falklands as the previous reports of rare and fragmentary fish material, in collections of the early 20thcentury Swedish expeditions and listed by Clarke (1913), refer to material that was never determined and may now be lost. Two specimens collected by W. Croft in 1947 and now held by the Natural History Museum, London, are probably a fish plate and spine, but are too poorly preserved to allow definitive identification.

The trilobites collected by the American Museum of Natural History expedition, from a number of sites in both East and West Falkland, were described by Carvalho (2006). In addition to the relatively abundant Homalonotid and Calmoniid trilobites, Carvalho noted the first definitive record of a Proetid trilobite, found at Pebble Island (West Falkland). Clarke (1913) had listed a possible *Proetus* sp. from Port Louis (East Falkland), identified from “two half pygidia, preserved on a single block of sandstone” that had been collected by Halle during the Swedish Magellanic Expedition, but the current whereabouts of this specimen is unknown and it may be lost. As an additional complication, Proetid trilobite nomenclature has been revised and expanded considerably since Clarke wrote. Amongst the Calmoniids, Carvalho described examples of *Metacryphaeus* cf. *M. caffer* from localities in both East and West Falkland; this is a new record for the Falkland Islands. Carvallho assigned a Pragian age to the trilobite fauna. The historical background to the discovery and nomenclature of the rare trilobite species *Metacryphaeus allardyceae* (Clarke 1913) was clarified by Stone (2009).

Bryozoa had not been previously recorded, but Stone and Rushton (2003) noted an encrustation of Trepostome Bryozoa on a fossil snail shell collected at Pebble Island (Figure 3a). The shell and its coating were contained in a carbonate concretion within Fox Bay Formation mudstone. The specimen is now held by The Natural History Museum, London. Another unusual addition to the Fox Bay Formation’s fossil fauna, a starfish-like ophiuroid, was described by Rushton and Stone (2011) but had been collected some years earlier at Fish Creek, 2.5 km north-east of Port Louis on the north side of Berkeley Sound, East Falkland. It is only the partial impression of the underside of the animal (Figure 3b) but seems likely to be from a previously undescribed species. The specimen is held at the Falkland Islands Museum in Stanley, with the Falkland Island Museum and National Trust inventory number 2589.

The brachiopod fauna from the Fox Bay Formation was utilised and figured by Cocks (2011) in a wide-ranging review of Palaeozoic faunal provinciality.

4 Lafonia Group

4.1 LITHOSTRATIGRAPHY AND PALAEOENVIRONMENT

The Lafonia Group was described in detail by Trewin and others (2002) in a publication that incorporated work carried out as part of a PhD project by Thomas (2001) at Aberdeen University. The contrary view of Meadows (1999) notwithstanding, a very close comparison was drawn between the Lafonia Group and part of the South African, Karoo Supergroup succession which it was felt strengthened the rotational model of the Falkland Islands' origins at the eastern margin of the Karoo Basin. Six points of close lithostratigraphical similarity were stressed.

- The glacigenic diamictities (Fitzroy and Dwyka tillites) are of identical appearance and lithofacies, and have compatible palaeocurrents.
- The glacial beds are overlain by organic-rich black mudstone.
- K-bentonites occur in the basin-floor successions.
- Interbedded basin-floor turbidite sandstone and rhythmite have a distinctive ichnofauna (see section 3.2 below).
- Coarsening-up delta-front sequences are overlain by fining-up channel sandstone units.
- Sandstones in both areas have a common provenance in a contemporaneous volcanic arc.

Trewin and others (2002) stress that in their reconstruction marine conditions would not be expected to occur above the level of the Fitzroy Tillite Formation, and that post-glacial sedimentation was essentially lacustrine.

The glacigenic Fitzroy Tillite Formation and the overlying Hells Kitchen Member at the base of the Port Sussex Formation were fortuitously sampled during mineral exploration drilling in East Falkland between 2005 and 2007. Borehole core illustrating the transitional 'deglaciation' succession was recovered back to UK (Stone 2011) and formed the basis of a M.Sc. research project at Cambridge University (Horan 2013), which was subsequently developed for publication (Horan *in press*). The research demonstrated that the Late Carboniferous to Early Permian 'Icehouse to Greenhouse' transition in the Falkland Islands was accompanied by cyclical waxing and waning of the Gondwanan, south polar ice sheet. The lithologies and sedimentary fabrics record a switch from deposition under a grounded ice sheet to glacio-lacustrine or glacio-marine deposition punctuated by minor episodes of ice advance and retreat during a period of net ice sheet retreat. X-Ray Fluorescence and reflectance data were used to quantify the change in terms of geochemical and geophysical properties respectively. Elements including zirconium, manganese, chromium, iron and titanium helped to constrain the cyclicity. Wavelet and spectral analyses demonstrated periodicities in the data that were suggestive of orbitally forced oscillations within the transition. This permitted the age modelling of a hypothetical time framework for the series spanning approximately 1.2 million years. The integrated approach of this research, which combined sedimentological data with geochemistry, gave a robust insight into this past climatic transition which may help to evaluate and inform predictions of future climate change.

Geochemical evidence for the non-marine deposition of the Black Rock Member (Port Sussex Formation) which conformably succeeds the Hells Kitchen Member was illustrated by López-Gamundí (2010, figure 8b). Two specimens were shown to have high Total Organic Carbon (13-15%) and low Sulphur content (<2%), a combination thought to be indicative of fresh-water salinity in the depositional environment. López-Gamundí interpreted the boundary between the Fitzroy Tillite Formation and the Port Sussex Formation in sequence stratigraphy terms as a transgressive ravinement surface that initiated a postglacial transgressive systems tract.

Horan's (in press) comparisons with other Gondwanan glacigenic successions suggest a Sakmarian (Early Permian) age for the transitional Hells Kitchen Member of the Port Sussex Formation. This is compatible with the Late Carboniferous or younger age for the Bluff Cove Formation, the unit immediately below the Fitzroy Tillite, reported by Aldiss and Edwards (1999) from the presence of sparse bisaccate pollen. However, Meadows (1999) refers to Devonian palynomorphs having been discovered during 'proprietary palynological dating'of the Bluff Cove Formation; no further details are given and reworking might be a possibilty.

Correlation of the Fitzroy Tillite Formation with the tillites of the South African Dwyka Group was further strengthened by the U-Pb dating of detrital zircons. The results were presented by Craddock and Thomas (2011) at a symposium in South Africa, but have not yet been formally published. The Fitzroy Tillite sample was described as 'massive tillite' collected 'west of Port Stanley'. Its zircon population (96 analysed zircons) showed major age peaks at around 550 Ma and 1100 Ma with minor contributions in the ranges 600 to 900 Ma and 2000 to 2700 Ma. These results were very closely matched by those from the Dwyka tillites of the Eastern Cape Province, South Africa.

4.2 BIOSTRATIGRAPHY AND PALAEONTOLOGY

An exotic contribution to Falkland Islands palaeontology followed the discovery of clasts of fossiliferous limestone (ranging up to 45 cm in maximum dimension) in the uppermost Carboniferous to Lower Permian Fitzroy Tillite Formation at Port Purvis and east of Hill Cove, both West Falkland, with smaller and rarer clasts found at Frying Pan Quarry, East Falkland. The limestone proved to contain a rich Early Cambrian (probably Botomian) fauna of archaeocyaths (Figure 3c), together with a radiocyath and a few trilobites, which has been described by Stone and Thomson (2005) and Stone and others (2012). Neither Cambrian strata nor limestone are present in the Falklands rock succession and the clasts are regarded as exotic erratics, introduced during the Permo-Carboniferous glaciation of southern Gondwana, prior to its Mesozoic break-up. Nineteen archaeocyath taxa have been identified, with seven (plus a radiocyath) occurring in a single clast. Trilobite identifications are less definitive but they are compared to *Yorkella* and the Siberian genera *Edelsteinaspis*, *Namanoia* and *Chondrinouyina*. The archaeocyath fauna has an Australo-Antarctic character and the Transantarctic Mountains seem the most likely source for these unusual erratics despite recent, tantalising archaeocyath discoveries in Argentina (González and others 2012), the first records from South America. In those reconstructions of Gondwana that rotate a Falklands microplate, it is moved into a position between South Africa and East Antarctica, in proximity with the Eastern Cape Province and the 'Atlantic' end of the Transantarctic Mountains. Tillites within the Permo-Carboniferous Dwyka Group of the Eastern Cape Province are correlatives of the Fitzroy Tillite Formation and also contain rare clasts of archaeocyathan limestone with a fauna similar to that seen in the Falkland Islands examples. The rotational reconstruction also produces a continuity of the apparent ice-flow directions in South Africa and the Falkland Islands.

The figured material from Stone and others (2012) has been lodged in The Natural History Museum, London. Additional samples of archaeocyathan limestone from the same localities have been incorporated into the collections of the British Geological Survey with registration details listed below. The numbers prefixed LX are the BGS accession numbers. The numbers prefixed PS are the working, field numbers that allow correlation with the clasts from which the figured specimens were derived and which contain the formally described faunas as held by The Natural History Museum. For ease of comparison, the details of the NHM specimens, as listed in Stone (2011) and in Stone and others (2012) are also included in this report as Appendix 2.

Frying Pan Quarry, East Falkland: [Lat. 51º 49' South; Long. 58º 20' West].
LX 1004-1 to 5 (= PS 303-1 to 5). Note that archeaocyaths have only been positively identified in LX1004-1 and 2; the limestone clasts numbered LX1004-3 to 5 may not be fossiliferous.

Old House Rocks, East Falkland: [Lat. 51º 45' South; Long. 58º 53' West].
LX1006-19. Borehole core specimen containing a clast of cleaved and deformed limestone with possible traces of archaeocyaths.

Fox Point West (east of Hill Cove), West Falkland: [Lat. 51º 29' South; Long. 60º 04' West].
LX1008-1 to 5 (= representative pieces from the five clasts PS304-4 to 304-8).
LX1073a, b (= two pieces from clastPS304-2)
LX1074a to e (= five pieces from clast PS304-3)
LX1075a to e (= five pieces from clast PS304-5)
LX1076 (= one piece from clast PS304-6)
LX1077a to f (= six pieces from clast PS304-7)
LX1078a to s (= nineteen pieces from clast PS304-8)

The fish-generated trace fossil *Undichna* had been noted from several localities within the outcrop of the Lafonia Group by Aldiss and Edwards (1999), but was the subject of an in-depth study by Trewin (2000). Several different species were described from the Brenton Loch Formation at Camilla Creek, 5 km north of Darwin (Figure 4), and from Sea Lion Island, both East Falkland, with some representative specimens now held by the Department of Geology and Petroleum Geology, University of Aberdeen. Trewin considered the environment of the traces' creation to be non-marine, and noted the close similarity of the Falklands ichnofauna to that of the Permian succession in the Eastern Cape Province, South Africa.

A non-marine depositional environment for the Brenton Loch Formation, and its South African association, was also supported by the discovery of a sparse bivalve fauna at Rory's Creek, on the southern shore of Choiseul Sound, East Falkland. The first specimen was recorded by Stone and Rushton (2003), and was described jointly with two subsequent small collections by Simões and others (2012). Prior to the discovery of the bivalves the only animal fossil known from the entire Lafonia Group was a remarkably preserved damselfly wing, found amidst the widespread *Glossopteris* flora by Halle during the Swedish Magellanic Expedition and described by Tillyard (1928); it is now held by the *Natur Historiska Riksmuseet* in Stockholm. The bivalves are associated with trace fossils and were collected from a bed in the upper part of the Brenton Loch Formation, within a 25 cm thick interval of dark siltstones and mudstones with planar lamination, overlain by more massive sandstones.The shells are commonly articulated, with the valves either splayed open (Figure 3d) or closed. At the top of the succession, mudstone beds nearly 1.5 m above the bivalve-bearing layers contain well-preserved *Glossopteris* sp. *cf. G. communis* leaf fossils. The closed articulated condition of some shells indicates preservation under high sedimentation rates with low residence time of bioclasts at the sediment/water interface. However, the presence of specimens with splayed shells is usually correlated to the slow decay of the shell ligament in oxygen-deficient bottom waters. The presence of complete carbonized leaves of *Glossopteris* close to the bivalve-bearing bed also suggests a possibly dysoxic-anoxic bottom environment with the bivalves preserved by abrupt burial, possibly by distal sediment flows into a lake.They are most probably autochthonous to parautochthonous fossil accumulations. The shells resemble those of anthracosiids and were assigned by Simões and others (2012) to *Palaeanodonta* sp. aff. *P. dubia*, a non-marine species also found in the Permian succession of the Karoo Basin, South Africa and thought to be indicative of a Middle Permian (Capitanian) age. Specimens are held by the British Geological Survey with the registered numbers LX1010-1 to LX1010-6; other specimens are held by the University of São Paulo, Brazil, under the prefix GP.

5 West Point Forest Bed

The origin of the West Point Forest Bed has been much debated. It is a clay layer packed with tree debris and found beneath solifluction deposits close to sea level on West Point Island, West Falkland (Figure 1). Halle (1911) had thought it to be the remains of an *in situ*, pre-glacial tree cover, whereas Baker (1924) concluded that it was simply a buried accumulation of driftwood. Subsequent investigations of the contained palynomorph assemblage, reviewed by Aldiss and Edwards (1999), favoured Halle but suggested a Tertiary age considerably older than he had anticipated, perhaps as far back as the Early Oligocene. More recently, a very detailed study by Macphail and Cantrill (2006) has supported the Tertiary interpretation, but indicated more specifically a slightly younger, Middle Miocene to Early Pliocene age. This was based on the time distribution of a number of rare pollen types and the present-day ecology of their nearest living relatives in South America and the Pacific region. The bed derives from a wet, temperate rainforest in which a variety of tall gymnosperms formed an overstorey above a closed canopy dominated by *Nothofagus* spp. An extinct, probably shrub-sized conifer appears to have formed the ground cover. It is highly likely that at the time of its growth this forest community covered much of the Falkland Islands.

Specimens of the West Point Forest Bed that had been collected in 1913 during a mineral prospecting exercise by David Ferguson (carried out on behalf of the Salvesen Whaling Company, then active in the Falklands) have recently been relocated in the Hunterian Museum, University of Glasgow (Stone and Faithfull 2013a). They are the best examples of the preserved wood known to exist in any museum collection (Figure 5).

6 Geological Structure

An unusual addition to the structural features of the Falkland Islands was the east-west sinistral shear zone noted by the author in February 1999, coincident with the steep shoreline of Ordnance Point to the north-east of Stanley (Figure 6). The strata affected are quartzites of the Port Stanley Formation. Steeply plunging to vertical folds, tight to isoclinal and ranging in wavelength and amplitude from 1 m up to about 20 m, occur in an east-west zone at least 30 m wide. The smaller folds commonly form syncline-anticline pairs indicating a consistent sinistral shear sense. The larger fold hinges (Figure 7) are generally isolated within an anastomosing fault network. The D1 fold hinges elsewhere in the area are sub-horizontal, but appear to steepen as the shear zone is approached. No details of the Ordnance Point shear zone have been published, but a summary report was lodged with the Department of Mineral Resources, Stanley, dated 15 February 1999. That report is reproduced here as Appendix 3.

Generally in recent years, the examination of the onshore structural geology of the Falkland Islands has been complementary to the more extensive analysis of the Late Jurassic and younger offshore basins. Much offshore seismic data is now available but most of the interpretations arising from their analysis are commercially confidential and unlikely to be generally available for some time.

Combining the available offshore data with onshore observations, Hyam and others (2000) established a structural history for the Falkland Sound Fault. They stressed the geological contrasts between East and West Falkland and from these established factors, together with new data on thermal maturity and kerogen facies, calculated a structural relief of 6–8 km across the Hornby Mountains anticline at the eastern margin of West Falkland (Figure 1). This has developed by intermittent downthrow to the south-east across a major sub-anticline fault from Devonian to Jurassic times. Velocity and gravity data from a seismic line to the south-west of the Falkland Islands was interpreted to show a similar basement structure to that underlying West Falkland. On this evidence the Falkland Sound Fault – or more properly the Hornby Mountains Fault – continues offshore as a series of en echelon fault segments for at least 60 km to the south-west of the archipelago. The conclusions presented were partly based on work carried out as part of a PhD project by Hyam (1997) at Southampton University.

Structural contrasts between East and West Falkland were also investigated by Thomson and others (2002) who used apatite fission track analysis and vitrinite reflectance data to establish a thermal history for the Falklands sedimentary succession. Three discrete episodes of heating and cooling were established. Initial cooling in the Late Permian was restricted to West Falkland and was the result of differential uplift and erosion of West Falkland relative to East Falkland. Subsequent Early Jurassic cooling of both East and West Falkland was associated with the plume-related thermal uplift that preceded the break-up of Gondwana and the opening of the Atlantic Ocean. There was then renewed heating during the Late Jurassic to Early Cretaceous interval that Thomson and others relate, most probably, to renewed burial, with the implication that the offshore basins originally extended onto the present-day onshore area. Late Cretaceous to Early Tertiary cooling followed as uplift and erosion accompanied regional structural developments at the margins of major offshore features on the Falklands Plateau.

There are two potentially significant adjuncts to the Late Jurassic to Early Cretaceous phase of heating indentified by Thomson and others (2002). Firstly, the discovery of Early Creatceous dykes since, at the time they wrote only Early Jurassic minor intrusions were known from the Falkland Islands. Subsequently, an Early Cretaceous dyke swarm was identified by Stone and others (2008) and correlated with magmatism in the offshore area by Richards and others (2013).

This extensional magmatism may well have contributed to an elevated Early Cretaceous heat flow. More information on the Cretaceous dykes is give below, in the next section of this report.

The second point to be made in the context of the thermal history proposed by Thomson and others (2002) relates to their proposal that the offshore basins originally encroached onto what is now the onshore area. As currently interpreted, there are no post-Permian strata present on the Falkland Islands, whilst the oldest strata known from the offshore basins are Jurassic. Here, speculatively, attention is drawn to the outcrop on the north coast of East Falkland of the Limpet Creek Member of the Port Stephens Formation. This unique unit was defined by Aldiss and Edwards (1998, 1999) who nevertheless noted its anomalous position and lithology – a relatively soft, brown micaceous sandstone contrasting with and apparently underlying the much harder quartzo-feldspathic sandstone of the main Port Stephens Formation. The latter is no younger than Early Devonian in age and may well be Silurian. The stratigraphical relationships are not well-defined and the outcrop of the Limpet Creek Member lies within a plexus of faults tranding north-west to south-east that would appear to link with the offshore faults defining the southernmost extremity of the North Falklands Basin (Figure 8). Perhaps it is just possible that the Limpet Creek Member is of Permian or Mesozoic age and comprises the youngest onshore strata, forming a faulted outlier linked to the succession in the offshore North Falkland Basin, rather than the oldest onshore strata, as a position at the base of the Port Stephens Formation would imply. Further investigation might prove fruitful.

In addition to the published studies of Falklands structural geology discussed above, the theme was also addressed in an unpublished PhD thesis by Hodgkinson (2002), completed at the University of Birmingham. Hodkinson recognised four phases of deformation (D1-4) with particularly significant results reported in association with the first and third. The main, south-verging fold and thrust belt that dominates the structure of northern East Falkland includes developments of foliated cataclasite within the thrust zones. Secondary, syn-tectonic mica within a cataclasite zone at Cow Bay (Figure 1) gave an Ar-Ar radiometric date of 278±8 Ma confirming initial (D1) deformation of the Falklands succession to have been active in the Early Permian. Hodgkinson’s second deformation phase (D2) was associated with formation of the Falkland Sound Fault. Thereafter, the intrusion of Early Jurassic dykes was syn-tectonic with a transtensional phase (D3) so that shear was imposed on the dykes during cooling and influenced the formation of minerals that were to be fundamental to palaeomagnetic modelling. This, Hodgkinson thought, cast doubt on the reliability of results previously used to establish the rotation of a Falklands microplate (Taylor and Shaw 1989), results that he was unable to replicate. Hodgkinson related the east-west sinistral shear zone at Ordnance Point and dextral shear along Falkland Sound Fault as conjugate D3 effects. The final phase of deformation (D4) was thought to involve normal reactivation of the D1 thrust structures as part of the regional, Cretaceous extension responsible for the development of the North Falklands Basin.

7 Mesozoic minor intrusions

A radical reinterpretation of the Falkland Islands dolerite dyke swarms was precipitated by an aeromagnetic survey flown in support of onshore mineral prospecting work. The results have allowed an improved discrimination of the principal swarms (Figure 9) and were augmented by radiometric dates and geochemical analyses of representative specimens. Most of the dykes previously described as forming a “north-south” swarm of Jurassic age are associated with a set of NE-SW linear magnetic anomalies that are entirely separate from another set of N-S to NNW-SSE anomalies. The NE-SW Jurassic dyke swarm occurs mostly in West Falkland but extends sparsely into East Falkland; a separate E-W dyke swarm, also of Jurassic age, is restricted to the southern part of West Falkland. The newly discovered N-S swarm spans West and East Falkland, and the offshore area to the south-east and has proved to be Early Cretaceous in age (Stone and others 2008; Richards and others 2013). The different dyke swarms, whilst all being broadly doleritic, are petrographically and geochemically distinct with, in particular, the Cretaceous dykes having a much higher Fe content than the Jurassic dykes. Ar-Ar age dating of East Falkland dykes has confirmed an Early Jurassic, ca 184-178 Ma, age for the NE-SW swarm, and has provided Early Cretaceous ages for the N-S orientated dyke swarm ranging from ca 135 Ma (Valanginian-Hauterivian) at Teal Creek and Peat Banks (Figure 9) to ca 121 Ma (Aptian) at Pony’s Pass Quarry; although it appears to be technically robust, on regional grounds the validity of the Aptian age at Pony’s Pass may be questionable (Richards and others 2013).

It has also been possible to suggest correlations between the onshore dyke swarms and evidence for magmatism in the offshore Falkland Plateau basin (Richards and others 2013). The onshore Jurassic dykes, and a possible correlative dolerite body forming seismic basement in the Falkland Plateau Basin, are associated with the regional Karoo-Ferrar magmatism, linked to the initial break-up of Gondwana. The Early Cretaceous onshore magmatism has the same age as that assigned from seismic interpretation to sills and/or lavas within the Falkland Plateau Basin sedimentary succession. Both the onshore and offshore Early Cretaceous magmatism is likely to be associated with the later extension phases of the Falklands Plateau and rifting of the North Falklands Basin as the South Atlantic Ocean initially opened.

Hodgkinson (2002) had questioned the validity of palaeomagnetic results from the dykes, and hence their use in support of a rotational model of a Falklands microplate. Nevertheless, an assessment of the asymmetry of the linear aeromagnetic anomalies associated with individual dykes (Stone and others 2009) supported the rotational model of a Falklands microplate. There is a contrast between the anomalies associated with the Jurassic dykes and those associated with the Cretaceous dykes that is best explained by the former having experienced a pre-Cretaceous, clockwise microplate rotation of about 120º. The Cretaceous dykes and the NW-SE Jurassic dykes show both normal and reversed magnetic polarity, the E-W Jurassic dykes have consistently normal polarity (Figure 9).

Details of representative dyke specimens held by the British Geological Survey have been provided by Stone (2013).

8 Peripheral literature

As a complement to the detailed, technical report on Falkland Islands geology by Aldiss and Edwards (1999), a shorter and more popular account was prepared by Stone and others (2005). In this booklet it was possible to introduce some recent discoveries that had not been available to Aldiss and Edwards, such as the archaeocyaths from the limestone clasts in the Fitzroy Tillite Formation, and the bivalve fossils from the Brenton Loch Formation. A shorter popular article describing the essentials of Falkland Islands geology was published by Stone (2010).

Historical aspects of the geological exploration of the Falkland Islands have arisen from newly discovered archive material and the re-examination of museum specimen collections. The way in which the museum fossil collections were acquired, and then utilised in the continental drift debate of the early 20th century, was described by Stone and Rushton (2012). The contributions made by Bartholomew Sulivan to Charles Darwin's (1846) account of the geology of the Falkland Islands were discussed by Stone and Rushton (2013). The geological interpretations made by David Ferguson in 1913-1914, during the first mineral prospecting exercise in the Falklands, were assessed by Stone and Faithfull (2013a, 2013b). In addition to these substantial papers, short articles celebrating some of the more entertaining and unusual aspects of the geological exploration of the Falkland Islands have appeared regularly in *Falkland Islands Journal*. Most can be accessed via www.nora.nerc.ac.uk/view/author/833.html.

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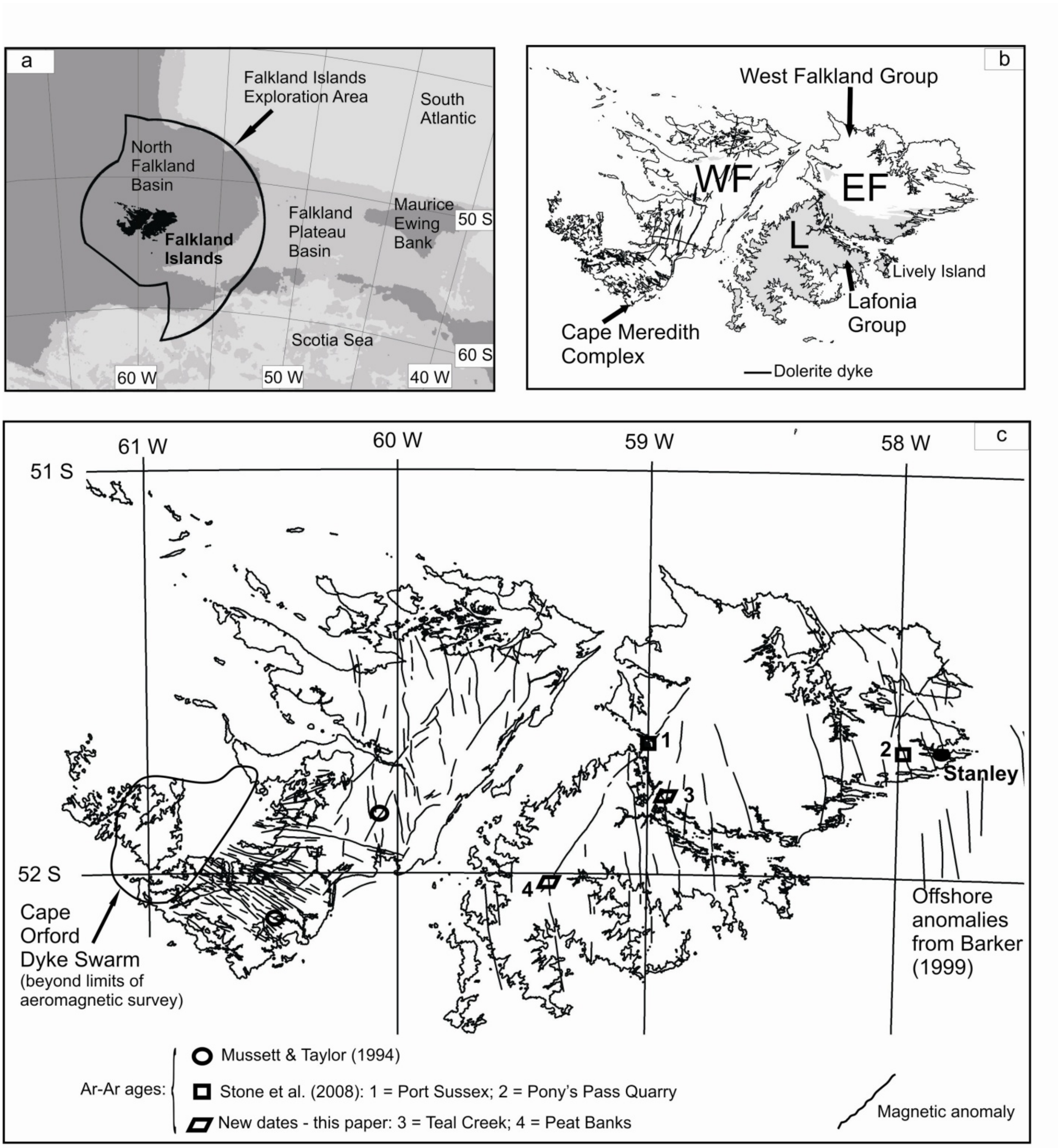


Figure 1 Location map and outline geology of the Falkland Islands after Richards and others (2013):

a. Regional setting at the western end of the Falkland Plateau, South Atlantic Ocean, with bathymetry represented by the grey scale from darkest = shallowest water (< 1500 m approximately) to palest = deepest water (>2500 m approximately).
b. Outrop areas for the West Falkland (unshaded) and Lafonia (pale grey) groups (WF = West Falkland, EF = East Falkland, L = Lafonia).
c. Linear aeromagnetic anomalies interpreted as dolerite dykes, showing the locations of analysed and dated dyke samples. Note that the aeromagnetic survey covered only the two main islands and extended neither to the western promontories of West Falkland nor to the smaller offshore islands.

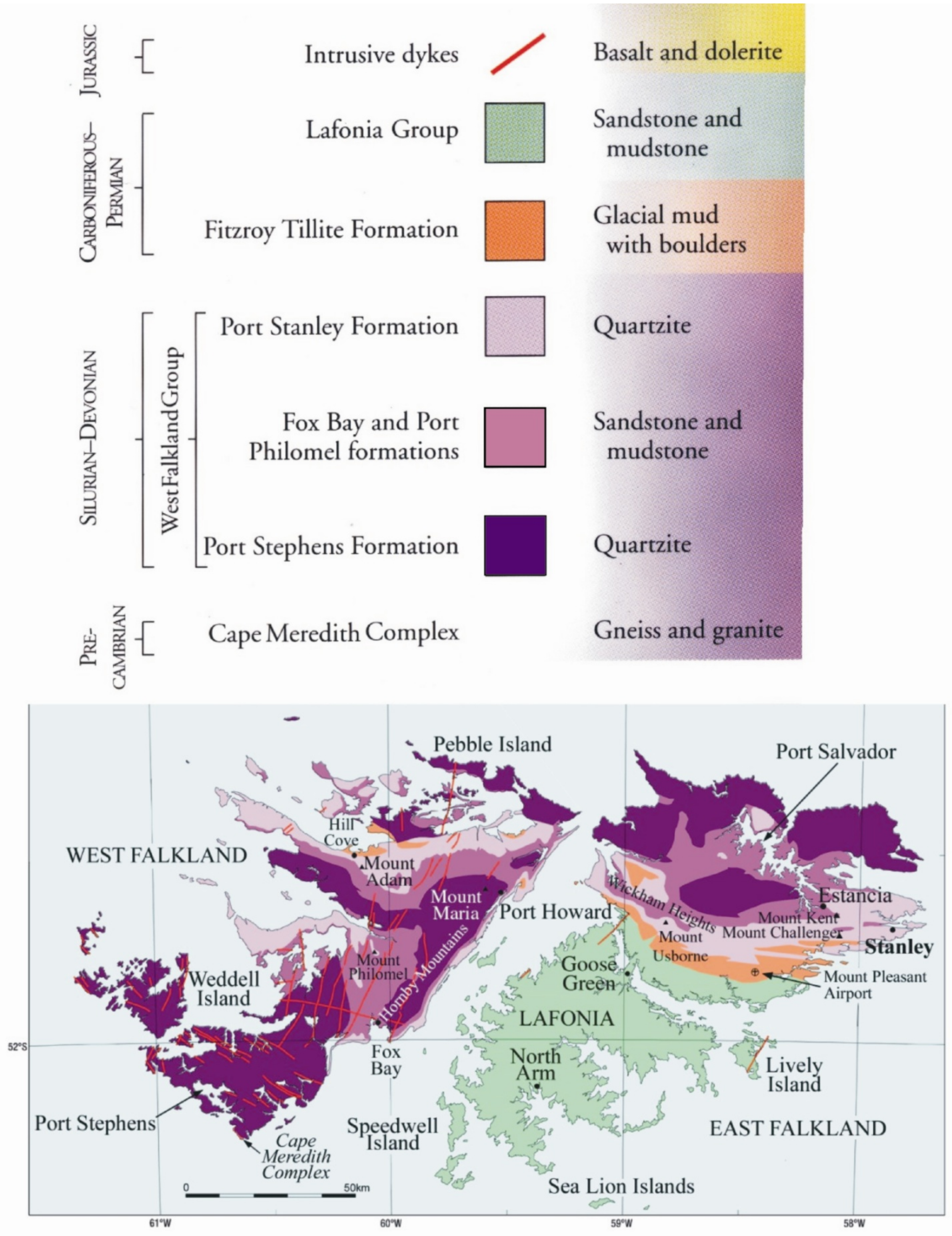
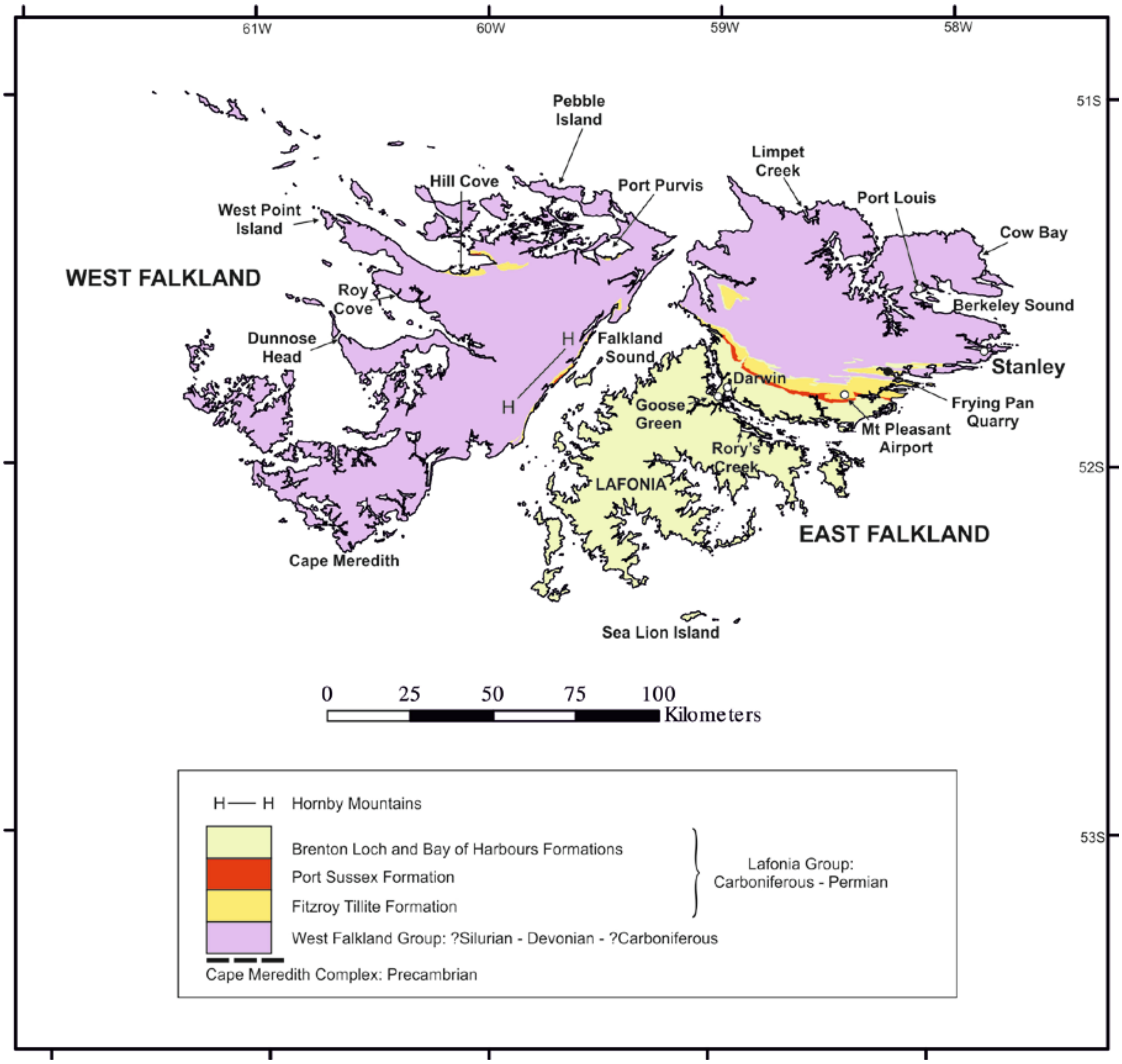


Figure 2 Geology and locality maps for the Falkland Islands:

a. Outline onshore geology after Aldiss and Edwards (1998).



b. Additional detail with the position of the principal localities mentioned in the text.

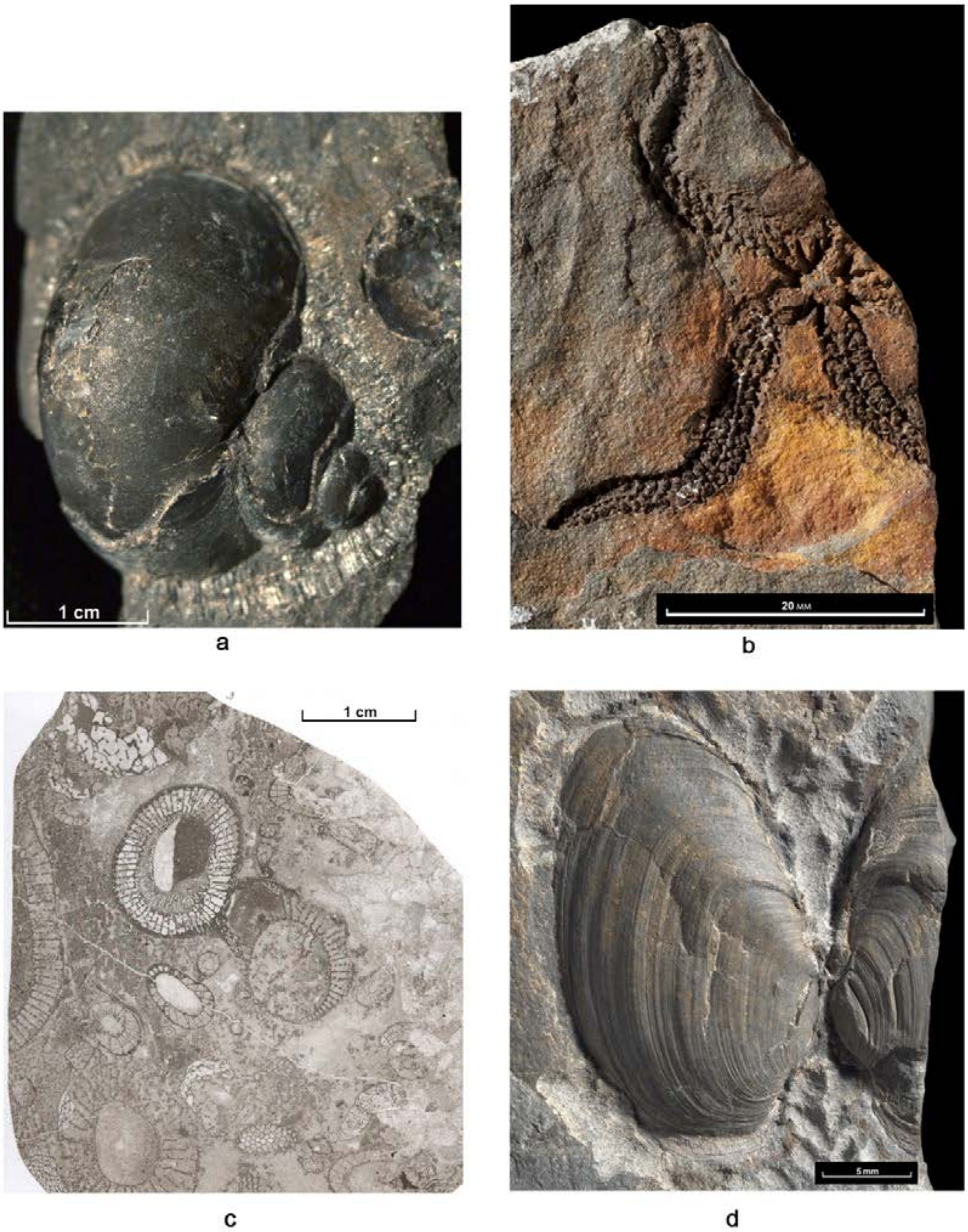


Figure 3 Some recent fossil discoveries from the Falkland Islands:

a. Bryozoa encrusting a snail shell from the Devonian Fox Bay Formation, Pebble Island, West Falkland. BGS image number P511902.
b. A starfish-like ophiuroid from the Devonian Fox Bay Formation, Fish Creek, Berkeley Sound, East Falkland. BGS image number 727089.
c. Early Cambrian archaeocyaths shown in a thin section from an erratic clast of limestone in the Early Permian Fitzroy Tillite Formation, Hill Cove, West Falkland. BGS image number P537735.
d. Bivalve shells resembling *Palaeanodonta* sp. aff. *P. dubia* from the Brenton Loch Formation at Rory's Creek, Victoria Harbour, East Falkland. BGS image number P573118.

Figure 4 The trace fossil *Undichna* from the Brenton Loch Formation, Camilla Creek, East Falkland.

Figure 5 Specimens of the Neogene wood from West Point Island, West Falkland, collected by David Ferguson in 1913 and now in the collection of the Hunterian Museum, University of Glasgow.

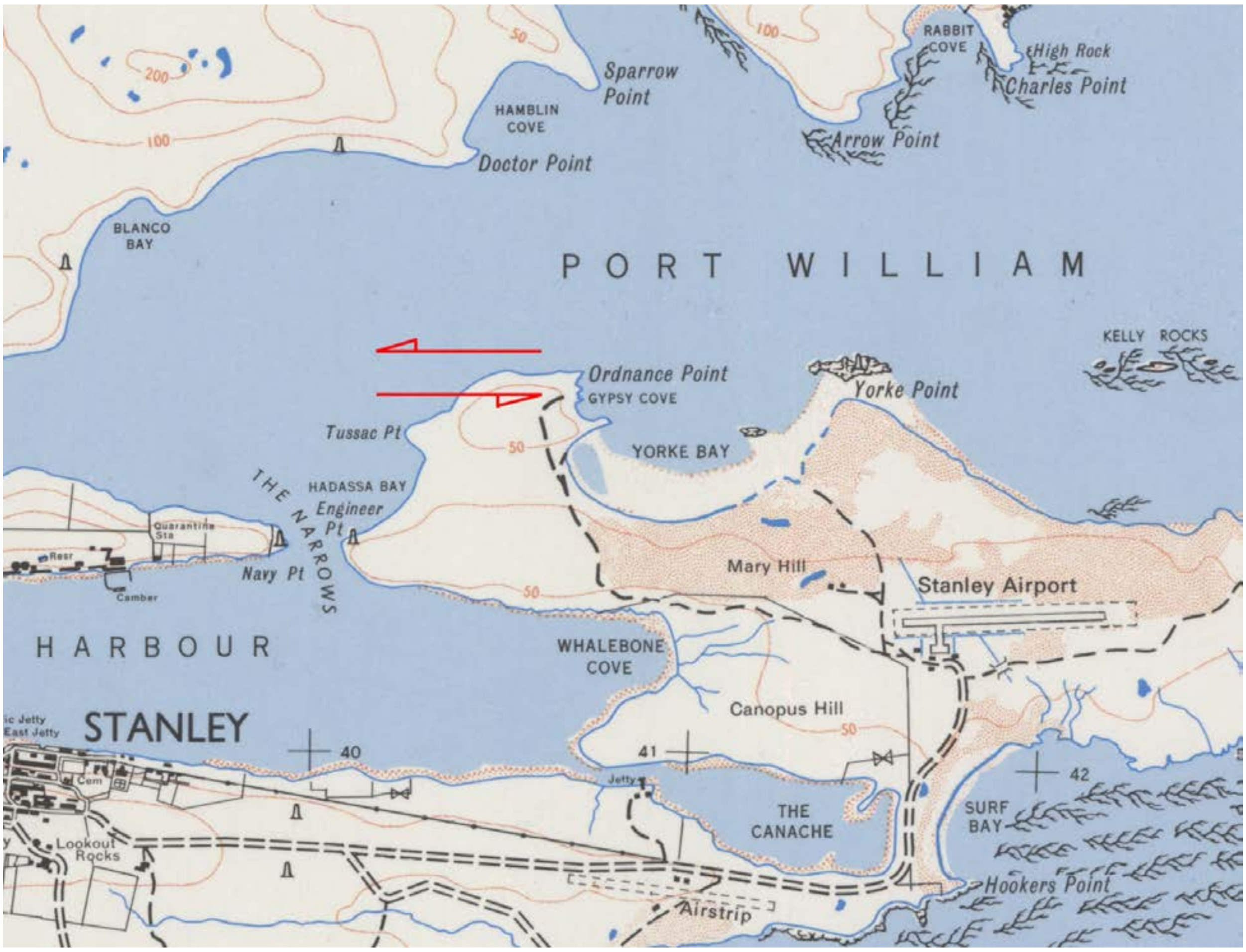


Figure 6 Location map for the Ordnance Point sinistral shear zone. Note that Yorke Point is currently inaccessible (within an Argentine minefield from the 1982 invasion) and so could not be checked for a likely continuation of the shear zone structures.

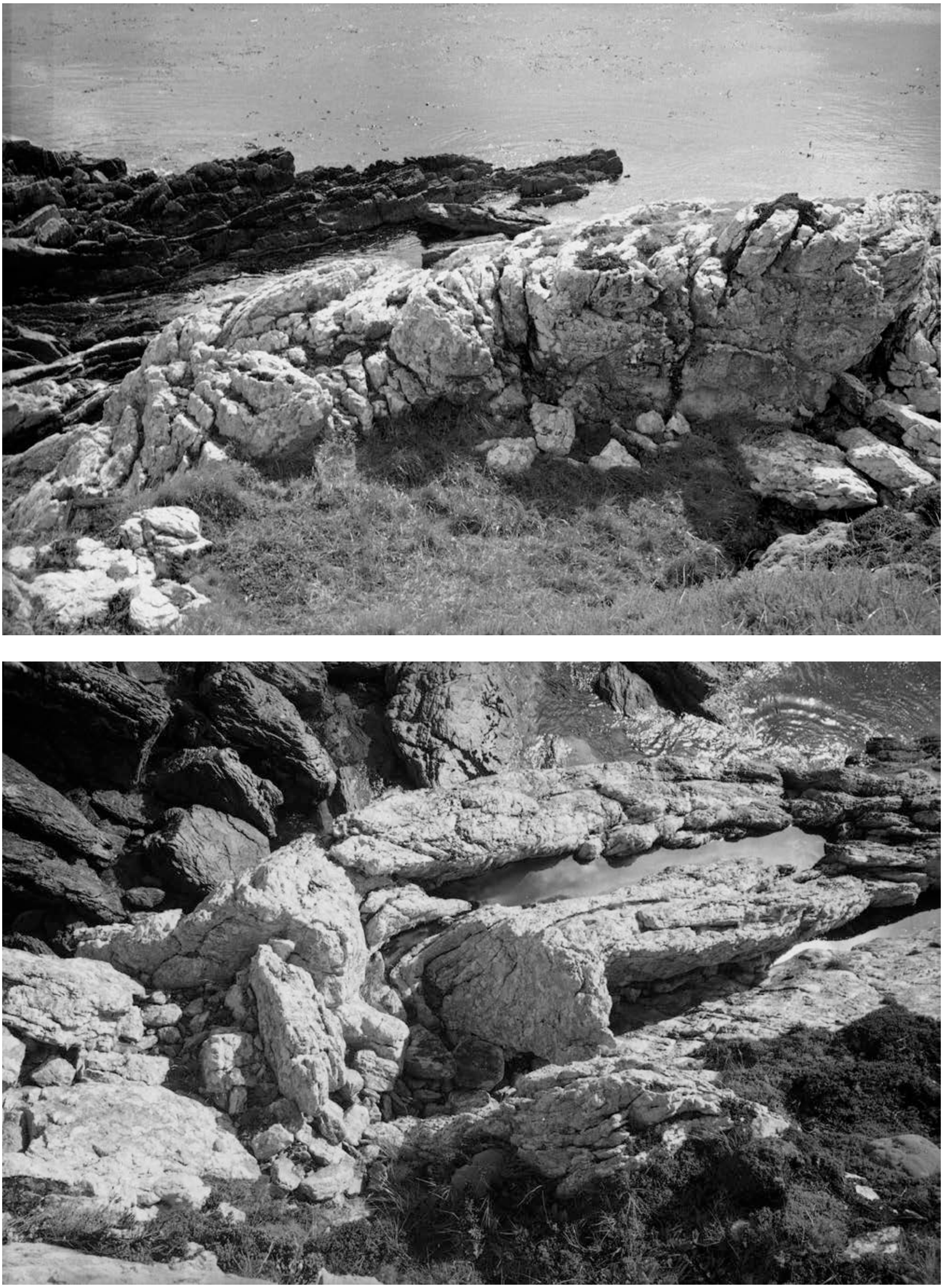


Figure 7 Two examples of steeply plunging fold hinges within the Ordnance Point sinistral shear zone.

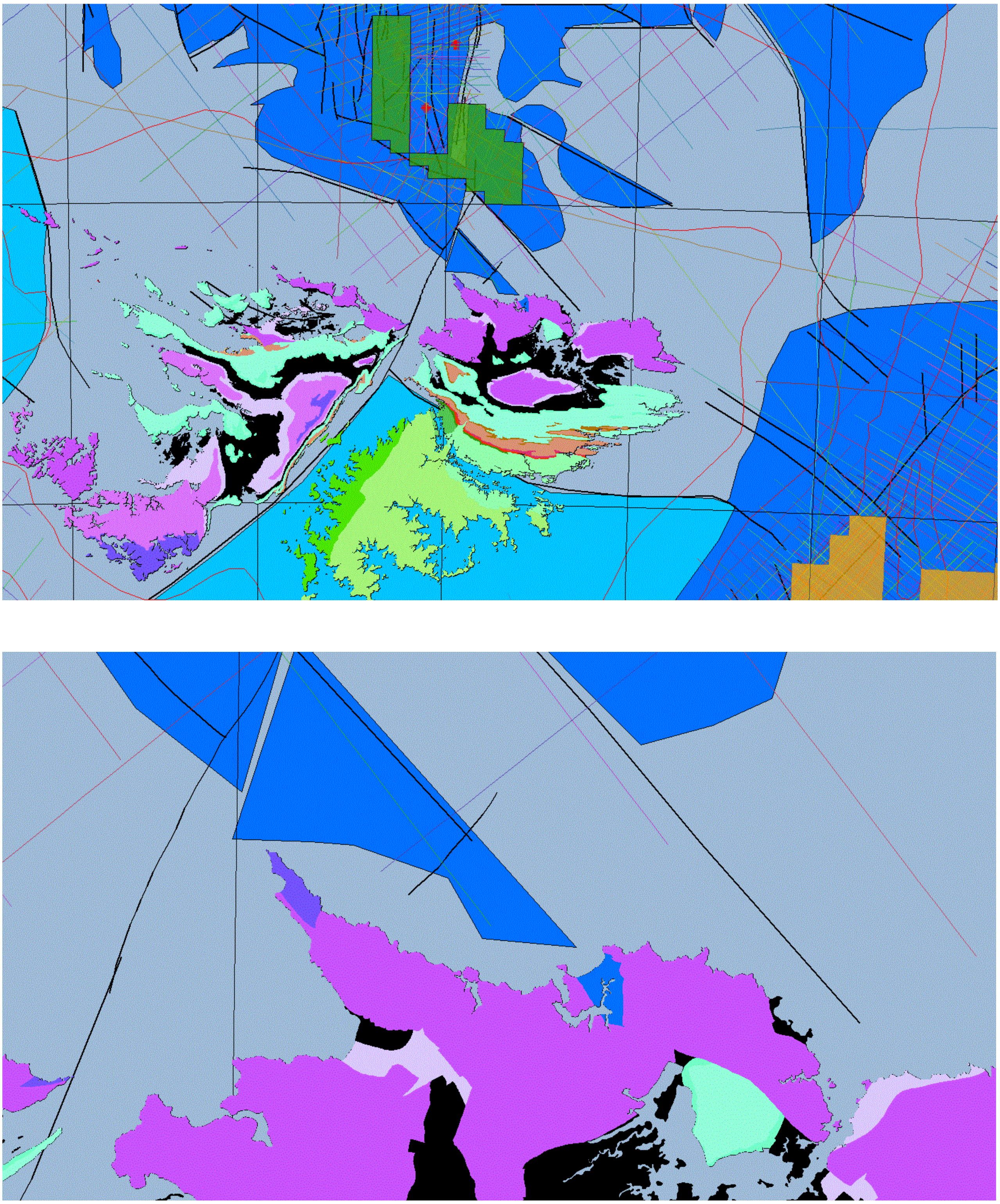


Figure 8 The onshore-offshore geological relationships at the north coast of East Falkland showing the spatial association of the Limpet Creek Member, supposedly forming the base of the Port Stephens Formation (cf. Figure 2), with the fault-controlled southern extremity of the North Falklands Basin. Figures provided by Dr Phil Richards.

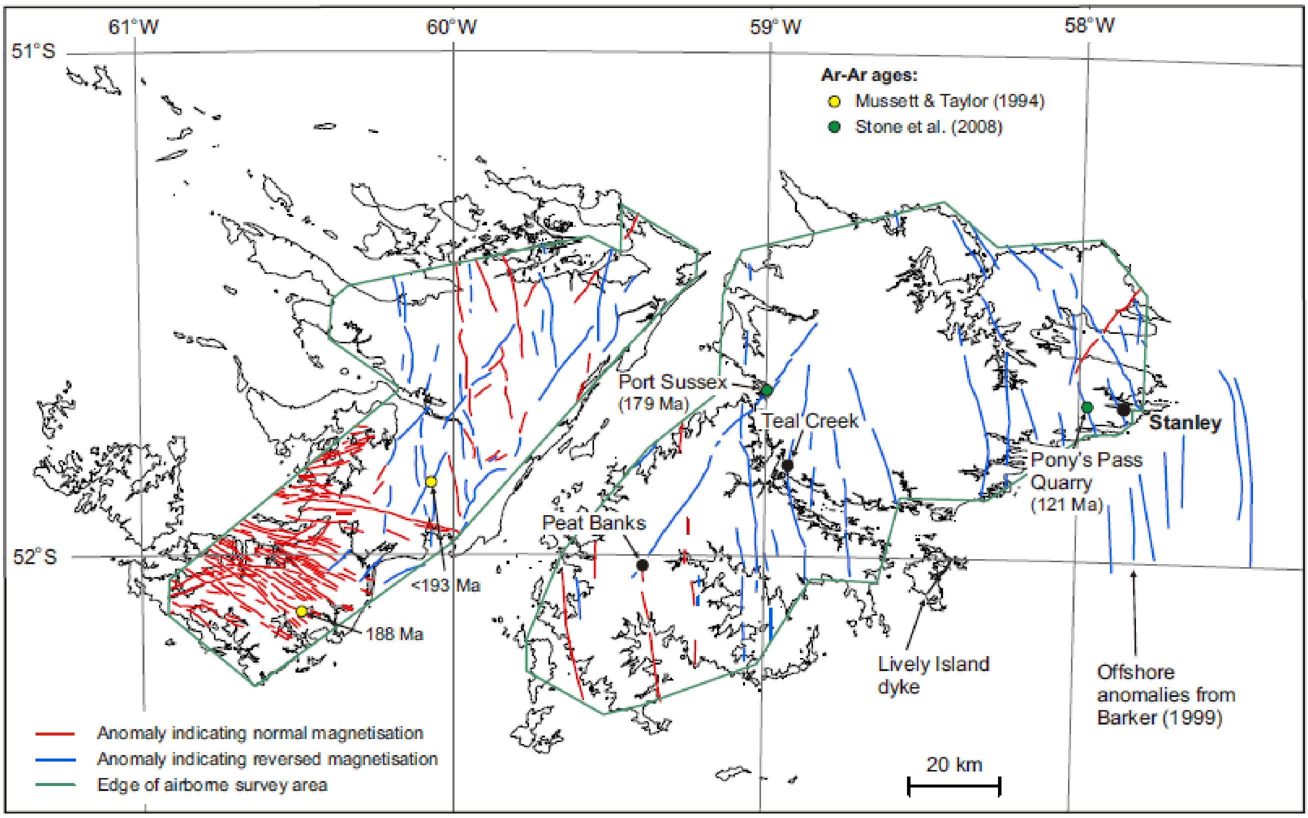


Figure 9 Linear magnetic anomalies, colour-coded to show normal (blue) or reversed (red) magnetization, as derived from the 2004 aeromagnetic survey of the Falkland Islands. The survey comprised north-south flight lines at a typical spacing of 0.5 km and east-west tie lines at a spacing of 5 km; the flying height was 120 m above ground surface. After Stone and others (2009).

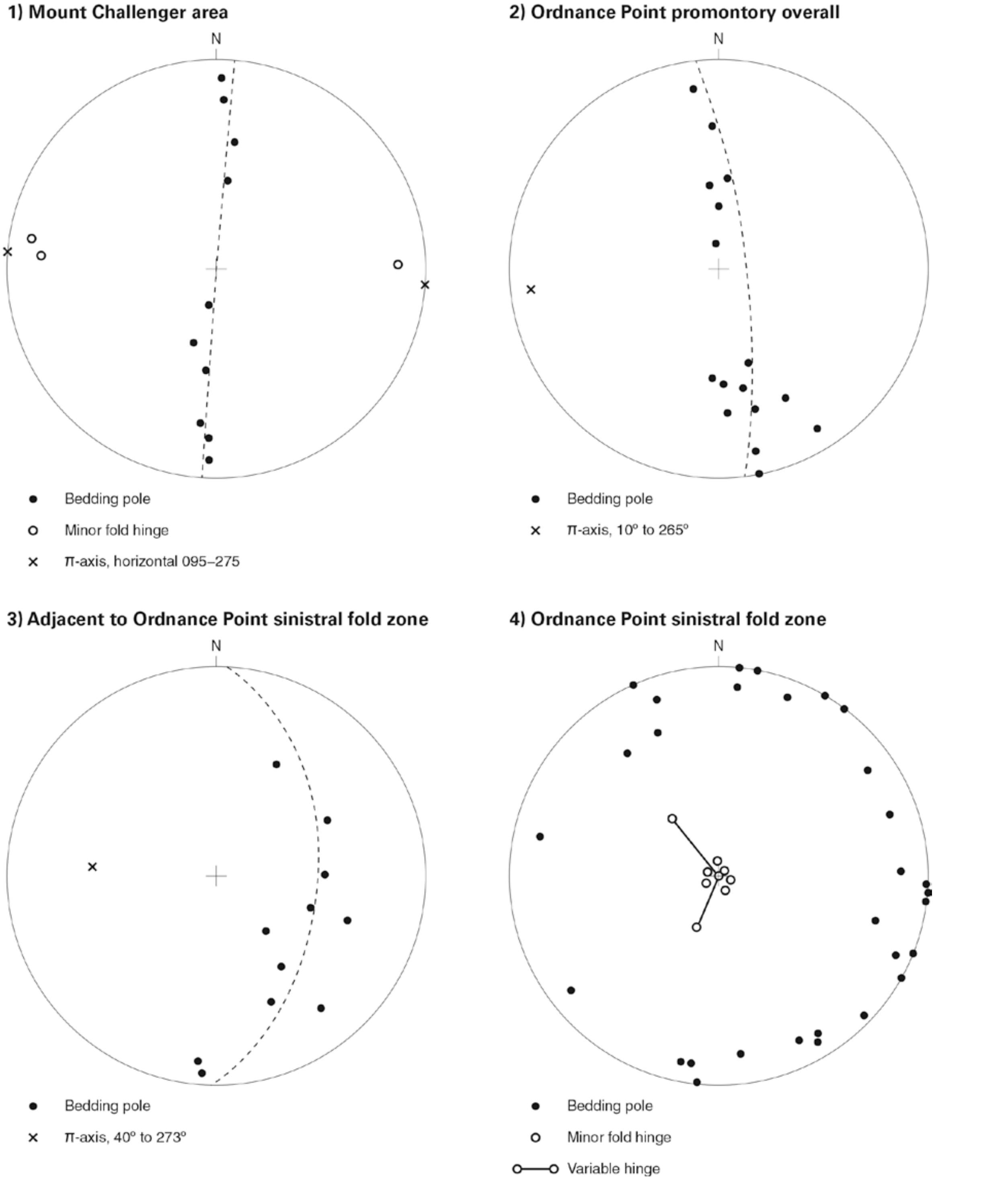


Figure 10 Four stereograms illustrating aspects of the geological structure associated with the Ordnance Point sinistral shear zone:

a. The regional fold attitude as illustrated by the Mount Challenger area, 20 km west of Stanley.
b. Fold attitude in the southern part of the Ordnance Point Promontory.
c. Fold attitude close to the Ordnance Point sinistral shear zone.
d. Fold attitude within the Ordnance Point sinistral shear zone.

Table 1 Lithostratigraphy of the West Falkland Group (Silurian to Devonian) and the Lafonia Group (Carboniferous to Permian). The maximum likely thickness of each formation is shown by the superscript figures after the formation name. After Aldiss and Edwards (1998, 1999), Trewin and others (2002), Hunter and Lomas (2003).

Lithostratigraphy	*Principal lithologies*	*Depositional environments*
Lafonia Group		
Bay of Harbours Fm.$^{3000\ \text{m}}$	Sandstone, mudstone	Delta top and channels
Brenton Loch Fm.$^{3000\ \text{m}}$	Sandstone, laminated mudstone	Deltaic and prodeltaic basin floor
Port Sussex Fm.$^{400\ \text{m}}$	Mudstone, sandstone, diamictite	Glaciomarine to marine or lacustrine
Fitzroy Tillite Fm.$^{850\ \text{m}}$	Massive diamictite	Glacial and glaciomarine
Bluff Cove Fm. $^{250\ \text{m}}$	Sandstone, mudstone	Shallow marine or proglacial deltaic
	Low-angle unconformity	
West Falkland Group		
Port Stanley Fm.$^{1100\ \text{m}}$	Quartz-sandstone, mudstone	Shallow marine and shoreface
Port Philomel Fm.$^{350\ \text{m}}$	Sandstone, mudstone	Deltaic to shallow marine
Fox Bay Fm.$^{1500\ \text{m}}$	Micaceous sandstone, mudstone	Marine inner shelf and shoreface
Port Stephens Fm.$^{2500\ \text{m}}$	Quartzo-feldspathic sandstone	Fluvial to intertidal and shoreface
	Major, angular unconformity	
Cape Meredith Complex	Proterozoic granite and gneiss, c. 1000 Ma	

Appendix 1 Representative lithostratigraphical reference specimens held by the British Geological Survey in the National Geoscience Date Centre, Keyworth, Nottingham.

West Falkland Group (LX1027 – LX1039):

LX1027. Port Stephens Formation, South Harbour Member. Borehole core specimen of pale grey, coarse-grained quartz sandstone. Seal Rookery Stream, north-west side of Port Edgar, West Falkland [51º 58’South, 60º 15’ West].

LX1028. Port Stephens Formation, Fish Creek Member. Coarse-grained quartz sandstone with small quartzose pebbles. Hawk Rock, near Saddle House, West Falkland [51º 39’South, 59º 56’ West].

LX1029. Port Stephens Formation. Pale grey, quartzo-feldspathic sandstone with *Skolithos* burrows. West side of Elephant Bay, Pebble Island, West Falkland [51º 18’South, 59º 35’ West].

LX1030. Port Stephens Formation. Pale grey, quartzo-feldspathic sandstone with *Skolithos* burrows. West side of Elephant Bay, Pebble Island, West Falkland [51º 18’South, 59º 35’ West].

LX1031. Fox Bay Formation. Laminated, yellow-brown micaceous sandstone with coquina of broken brachiopod shells and crinoid ossicles. Canard Cove, Port Louis Harbour, Berkeley Sound, East Falkland [51º 33’South, 58º 09’ West].

LX1032. Fox Bay Formation. Laminated, yellow-brown micaceous sandstone with coquina of broken brachiopod shells and crinoid ossicles. Canard Cove, Port Louis Harbour, Berkeley Sound, East Falkland [51º 33’South, 58º 09’ West].

LX1033. Port Philomel Formation. Fine-grained, yellow-brown micaceous sandstone with carbonised plant fragments. East side of San Carlos Water, East Falkland [51º 33’South, 59º 02’ West].

LX1034. Port Stanley Formation Pale grey quartzite with cross-lamination picked-out by mud laminae. Mary Hill, near Stanley, East Falkland [51º 41’South, 57º 47’ West].

LX1035. Port Stanley Formation Pale grey quartzite with cross-lamination picked-out by mud laminae. Yorke Point, Port William, East Falkland [51º 41’South, 57º 47’ West].

LX1036. Port Stanley Formation. Pale grey quartzite containing small mudstone flakes and a scattering of detrital heavy minerals (probably rutile).Two Sisters, East Falkland [51º 41'South, 58º 00' West].

LX1037. Port Stanley Formation. Laminated carbonaceous siltstone interbedded with fine-grained quartz sandstone. Long Pond, Bold Point, East Falkland [51º 26'South, 58º 27' West].

LX1038. Port Stanley Formation. Carbonaceous silty mudstone from an interbed with quartzite. Pony's Pass Quarry, near Stanley, East Falkland [51º 41'South, 57º 47' West].

LX1039. Port Stanley Formation. Carbonaceous mudstone with plant remains, from an interbed with quartzite. Pony's Pass Quarry, near Stanley, East Falkland [51º 41'South, 57º 47' West].

Lafonia Group (LX1040 – LX1072)

LX1040. Fitzroy Tillite Formation. Laminated diamictite cut by strong, penetrative cleavage. Memorial Cove, Fitzroy, East Falkland [51º 47'South, 58º 13' West].

LX1041. Fitzroy Tillite Formation. Massive diamictite, cleaved. Frying Pan Quarry, East Falkland [51º 49'South, 58º 19' West].

LX1042. Fitzroy Tillite Formation. Massive diamictite. Frying Pan Quarry, East Falkland [51º 49'South, 58º 19' West].

LX1043. Shepherds Brook Member, Port Sussex Formation. Fine grained, silty sandstone. Port Sussex, East Falkland.[51º 40'South, 58º 58' West].

LX1044. Black Rock Member, Port Sussex Formation. Black, carbonaceous mudstone. Ceritos Arroyo, East Falkland [51º 46'South, 58º 50' West].

LX1045. Terra Motas Member, Brenton Loch Formation. Sandstone showing grading from mud-flake conglomerate to fine grained, laminated sandstone. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1046. Terra Motas Member, Brenton Loch Formation. Dark grey, siliceous sandstone. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1047. Terra Motas Member, Brenton Loch Formation. Laminated siltstone with variable sandstone interbeds. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1048. Terra Motas Member, Brenton Loch Formation. Laminated siltstone with variable sandstone interbeds. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1049. Terra Motas Member, Brenton Loch Formation. Laminated siltstone with variable sandstone interbeds. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1050. Terra Motas Member, Brenton Loch Formation. Laminated siltstone and mudstone with bioturbation. Canada Runde Quarry, Black Rock, East Falkland [51º 49'South, 58º 41' West].

LX1051. Saladero Member, Brenton Loch Formation. Fine to medium grained sandstone. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1052. Saladero Member, Brenton Loch Formation. Fine to medium grained sandstone. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1053. Saladero Member, Brenton Loch Formation. Fine to medium grained sandstone. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1054. Saladero Member, Brenton Loch Formation. Fine grained sandstone with wispy cross-bedding picked out by muddy laminae. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1055. Saladero Member, Brenton Loch Formation. Fine grained sandstone with wispy cross-bedding picked out by muddy laminae. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1056. Saladero Member, Brenton Loch Formation. Fine grained sandstone with wispy cross-bedding picked out by muddy laminae. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1057. Saladero Member, Brenton Loch Formation. Laminated silty mudstone. Salinas Beach, near Goose Green, East Falkland [51º 49'South, 59º 00' West].

LX1058. Saladero Member, Brenton Loch Formation. Sandstone with silty laminations. Walker Creek, East Falkland [51º 58' South, 58º 47' West].

LX1059. Saladero Member, Brenton Loch Formation. Sandstone with mudstone laminations. Walker Creek, East Falkland [51º 58' South, 58º 47' West].

LX1060. Saladero Member, Brenton Loch Formation. Fine grained sandstone. Miles Creek, Victoria Harbour, East Falkland [51º 57’ South, 58º 52’ West].

LX1061. Saladero Member, Brenton Loch Formation. Medium grained sandstone. Arrow Harbour, Choiseul Sound, East Falkland [51º 54’ South, 58º 57’ West].

LX1062. Bay of Harbours Formation. Medium-grained sandstone. Colorado Pass, Lafonia, East Falkland [51º 53’ South, 59º 08’ West].

LX1063. Bay of Harbours Formation. Laminated, fine- to medium-grained sandstone. Cobb’s Pass, Bodie Creek, Lafonia, East Falkland [51º 50’ South, 59º 07’ West].

LX1064. Bay of Harbours Formation. Muddy siltstone with plant fragments. Motley Point, Lafonia, East Falkland. [52º 06’ South, 58º 41’ West].

LX1065. Bay of Harbours Formation. Coarse grained sandstone (interbedded with LX1066). Sound House, Lafonia, East Falkland [51º 59’ South, 59º 16’ West].

LX1066. Bay of Harbours Formation. Silty, fine grained sandstone (interbedded with LX1065). Sound House, Lafonia, East Falkland [51º 59’ South, 59º 16’ West].

LX1067. Bay of Harbours Formation. Muddy siltstone. Motley Point, Lafonia, East Falkland. [52º 06’ South, 58º 41’ West].

LX1068. Bay of Harbours Formation. Coarse-medium grained lithic sandstone. Bleaker Island, East Falkland [52º 11’ South, 58º 51’ West].

LX1069. Egg Harbour Member, Bay of Harbours Formation. Medium grained sandstone. Between Dos Lomas and New Haven, Lafonia, East Falkland [51º 46’ South, 59º 14’ West].

LX1070. Egg Harbour Member, Bay of Harbours Formation. Medium grained sandstone. New Haven [51º 45’ South, 59º 12’ West].

LX1071. Cantera Member, Brenton Loch Formation. Laminated siltstone/mudstone. Camilla Creek, East Falkland [51º 47’ South, 58º 58’ West].

LX1072. Cantera Member, Brenton Loch Formation. Laminated siltstone/mudstone. Teal Creek, Darwin Harbour, East Falkland [51º 49’ South, 58º 56’ West].

Appendix 2 Correlation of working, image and NHM catalogue numbers for the archaeocyath-bearing limestone clasts.

Working number: field collecting localities (Fig. 1) are identified as PS 218 (Port Purvis, West Falkland), PS 303 (Frying Pan Quarry, East Falkland) and PS 304 (Hill Cove, East Falkland); individual clasts collected (when more than one) are identified by the number following the hyphen, e.g. PS 304-8; where more than one thin section was cut from each clast, they are identified by letter, e.g. PS 304-8b; thin sections cut orthogonal to each other are identified by a superscript 1, e.g. PS 304-8b and PS 304-8b^1.

Description: HS = hand specimen; TS = thin section, standard format unless specified as (large), in which case the section is twice the standard size.

BGS image number: reference number for the scanned image of each thin section held in the photographic archive of the British Geological Survey.

NHM catalogue number: Palaeontological Department collection, a dollar sign ($) following the number indicates a thin section.

Working number	Description	BGS image number	NHM catalogue number
PS 218	HS	P 511905, 511906	NHM PI PO 12074
	TS	P 593184	NHM PI PO 12075$
PS 303-1	HS		NHM PI PO 12076
	TS	P 601007	NHM PI PO 12077$
PS 303-2	HS		NHM PI PO 12078
	TS	P 601008	NHM PI PO 12079$
PS 304-1	HS		NHM PI PO 12080
304-1a	TS (large)	P 601009	NHM PI PO 12081$
304-1b	TS	P 601010	NHM PI PO 12082$
304-1c	TS	P 601011	NHM PI PO 12083$
PS 304-2	HS		NHM PI PO 12084
	TS		NHM PI PO 12085$
PS 304-3	HS		NHM PI PO 12086
304-3a	TS	P 601012	NHM PI PO 12087$
304-3b	TS	P 601013	NHM PI PO 12088$
304-3c	TS (large)	P 537735	NHM PI PO 12089$
304-3d	TS		NHM PI PO 12090$

PS 304-4	HS		NHM PI PO 12091
	TS (large)	P 601014	NHM PI PO 12092$
PS 304-5	HS		NHM PI PO 12093
304-5a	TS	P 601015	NHM PI PO 12094$
304-5b	TS	P 601016	NHM PI PO 12095$
PS 304-6	HS		NHM PI PO 12096
	TS	P 601017	NHM PI PO 12097$
PS 304-7	HS		NHM PI PO 12098
304-7a	TS	P 601018	NHM PI PO 12099$
304-7a[1]	TS	P 601019	NHM PI PO 12100$
304-7b	TS	P 601020	NHM PI PO 12101$
304-7c	TS	P 601021	NHM PI PO 12102$
PS 304-8	HS		NHM PI PO 12103
304-8a	TS (large)	P 601022	NHM PI PO 12104$
304-8a[1]	TS (large)	P 601023	NHM PI PO 12105$
304-8b	TS (large)	P 601024	NHM PI PO 12106$
304-8b[1]	TS (large)	P 601025	NHM PI PO 12107$
304-8c	TS	P 601026	NHM PI PO 12108$
304-8d	TS	P 601027	NHM PI PO 12109$
304-8e	TS	P 601028	NHM PI PO 12110$

Appendix 3 Notes on the zone of steeply plunging folds at Ordnance Point

Field report deposited with the Department of Mineral Resources, Stanley, Falkland Islands, in February 1999. The four stereograms that accompanied the original report are reproduced here as Figure 10.

Steeply to vertically plunging, tight to isoclinal folds occur in an east-west zone trending west from Ordnance Point, the headland to the north-west of Yorke Bay and Gypsy Cove. The folds are seen at the foot of the cliffs, which form the southern margin of the zone, and in the rocks around sea level. The northern margin of the zone is not seen but it is at least 30 m wide, across strike. The folds range in wavelength and amplitude from less than 1 m up to about 20 m. One isolated area of anomalous bedding strike suggests the presence of a larger fold with wavelength up to about 50 m. The larger folds tend to be cut up by a broadly east- west, anastomosing and vertical fault system so that only isolated hinges are seen. The smaller folds commonly form complete anticline-syncline pairs with a consistent sinistral vergence, i.e. they are of "S" pattern looking down plunge. Fold style is mostly tight to isoclinal but there are some more open flexures of strike, still with sinistral vergence.

The Fl fold geometry south and inland from the Ordnance Point sinistral zone is the same as that seen elsewhere along strike in the folded Port Stanley Formation rocks. Stereogram 1 shows comparative data from the Mount Challenger area with data from the area south of the Ordnance Point zone summarised in stereogram 2. There is no significant difference in the overall F 1 fold pattern, which has been illustrated elsewhere by, for example, Curtis and Hyam. However, close to the Ordnance Point zone there is a tendency for the Fl hinge plunge to increase to moderate and westerly. This is illustrated in stereogram 3. Some of the spread in bedding poles plotted on steteogram 2 might be a precursor to this development. There is then an abrupt northwards change in hinge plunge into the Ordnance Point zone; in one case an Fl hinge plunging west at about 30 degrees is only 2 m across strike from a series of vertically plunging folds. Structural geometry in the zone of steeply plunging folds is illustrated in Stereogram 4. The plunge of some minor hinges is quite variable.

There are two possible mechanisms for the production of the Ordnance Point sinistral zone:

Progressive but irregular steepening of F 1 hinges, northwards across strike, until they become vertical. There has apparently been some such steepening towards the Ordnance Point zone. It would most likely have occurred in association with lateral east-west shear but the sense of that shear would not be recorded in the preserved fold geometry.

Folding subsequent to Fl in association with sinistral shear, perhaps with some steepening of adjacent F 1 hinges.

The evidence is permissive of either explanation but I favour the second on two rather weak counts. Firstly, the intensity of folding (and local variation in hinge plunge) is much greater in the Ordnance Point zone than is the case in F 1 fold zones elsewhere; this reasoning is a bit subjective. Secondly, there is one possible example of a minor Fl hinge with a moderate plunge refolded about a steeply plunging hinge; the relationships are not clear and could do with careful re-examination. If the east-west sinistral shear interpretation is correct, it probably occurred as a D3 phenomenon conjugate with the dextral, NE-SW lateral shear recognised particularly in the Falkland Sound area. The regional east-west strike of the Port Stanley Formation quartzite beds would have provided a strong pre-existing control on movement so the Ordnance Point zone could be contemporary with NW-SE sinistral D3 faults which have been sporadically recorded elsewhere. However, I do not think that steeply or vertically plunging folds have been previously observed so they may represent an additional structural element in the regional pattern.

Phil Stone

15 February 1999